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Winter circulation weather types and hospital admissions for respiratory diseases in Galicia, Spain

D. Royé[1] · J. J. Taboada[2] · A. Martí[1] · M. N. Lorenzo[3]

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Abstract The link between various pathologies and atmospheric conditions has been a constant topic of study over recent decades in many places across the world; knowing more about it enables us to pre-empt the worsening of certain diseases, thereby optimizing medical resources. This study looked specifically at the connections in winter between respiratory diseases and types of atmospheric weather conditions (Circulation Weather Types, CWT) in Galicia, a region in the north-western corner of the Iberian Peninsula. To do this, the study used hospital admission data associated with these pathologies as well as an automatic classification of weather types. The main result obtained was that weather types giving rise to an increase in admissions due to these diseases are those associated with cold, dry weather, such as those in the east and south-east, or anticyclonic types. A second peak was associated with humid, hotter weather, generally linked to south-west weather types. In the future, this result may help to forecast the increase in respiratory pathologies in the region some days in advance.

✉ D. Royé
dominic.roye@usc.es

J. J. Taboada
juan.taboada@meteogalicia.es

[1] Facultad de Geografía e Historia, Departamento de Geografía, Universidad de Santiago de Compostela, Praza da Universidade 1, 15782, Santiago de Compostela, Spain

[2] Consellera de Medio Ambiente, Territorio e Infraestruturas, Meteogalicia, Rúa Roma 6, 15707, Santiago de Compostela, Spain

[3] Facultad de Ciencias, Departamento de Física Aplicada, Universidad de Vigo, Campus As Lagoas, 32004 Ourense, Spain

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Introduction

The human body and atmospheric conditions are in a state of constant physical and chemical interaction. All human beings are obliged to react to the elements in their immediate surroundings so they can find a balance and ensure correct and optimum organic function. Of all the epidemiological studies focusing on the relation between weather-climate and human health, leading examples are those that analyse the impact caused by thermal stress from heat or cold (Tobías et al. 2014; Ye et al. 2012; Michelozzi et al. 2009; Basu 2009; Baccini et al. 2008; Hassi 2005), air pollution (Pope and Dockery 2014; Cesaroni et al. 2014; Carracedo-Martínez et al. 2010; Maté et al. 2010; Makria and Stilianakisa 2008), and airborne allergens (Khwarahm et al. 2014; Newnham et al. 2013; Carracedo-Martinez et al. 2008; Shea et al. 2008; Erbas et al. 2007; Breton et al. 2006; Tobías et al. 2003). Each impact by itself has negative effects in the human health. Hence, within the context of the thermal environment, the two last confounding variables mentioned are relevant for explaining the effects observed on morbi-mortality. In Spain, several studies are linking hospital admissions and environmental variables (e.g. Olcina Cantos and Martín Estúvez 2012; Linares and Díaz 2008, 2010; Ballester et al. 2006; Díaz et al. 1999, 2007; Lage Ferrón et al. 1999). But considerably more studies are related to mortality (e.g. Tobías et al. 2014; Gómez-Acebo et al. 2012; Maté et al. 2010; Raga et al. 2010; Taracido Trunk et al. 2009; Borrell et al. 2006; Díaz et al. 2006). The seasonal behaviour of morbi-mortality, especially pronounced in respiratory

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pathologies, shows clear increases during the winter and minimum values in summertime (Montero et al. 2010; Raga et al. 2010; Analitis et al. 2008; Díaz et al. 2005). When they are superimposed on seasonal cycles, peaks of higher morbi-mortality can be seen in periods of extreme temperatures or when there are high concentrations of pollution or pollen (Maté et al. 2010; Analitis et al. 2008; Baccini et al. 2008). The seasonal causes of infectious diseases, and more specifically in respiratory pathologies such as influenza, for example, cannot be attributed to one single factor (Fernández de Arróyabe 2012). They involve a complex interaction of many factors, such as environmental factors acting on human beings or pathogens, vectors and host, as well as behavioural and socioeconomic factors (Fisman 2007). There are many issues yet to be clarified on the subject of these kinds of seasonal behaviour. However, the effects of exposure to atmospheric changes and climatic elements can present a significant risk to some groups in the population because of their greater vulnerability. There is some evidence on the impact of certain atmospheric conditions on pre-existing respiratory pathologies, such as asthma and pneumonia (Viegas et al. 2004; Hajat et al. 1999). Additional groups considered to be at risk are elderly people, children and people with chronic diseases (Montero et al. 2012; Kovats and Hajat 2008; Analitis et al. 2008; Hajat et al. 2007). The complexity of the research lies in the fact that atmospheric elements (air temperature, humidity, atmospheric pressure, solar radiation, etc.) condition the environment simultaneously and are characterized by being interrelated with possible synergistic effects; in turn, these elements also influence other variables that affect health, such as the concentration of pollutants in the air (Kalkstein 1991). The difficulty therefore lies in the attempt to reduce the huge variety of conditioning factors to just a few relevant or dominant factors (Jendritzky 1993). One of the most commonly used methods to resolve this difficulty is to use the synoptic climatological approach (McGregor et al. 1999; Jamason et al. 1997). This enables all the atmospheric elements and factors to be included in a single indicator (Pablo et al. 2009; Kalkstein 1991). Specifically, air masses, with their particular defining features, reflect all the atmospheric effects on the territory at regional level. Studies carried out using the synoptic approach in Spain by (Pablo et al. 2009, 2013) for the city of Salamanca and for the autonomous region of Castile-La Mancha, showed clear evidence of a connection between certain types of weather (for example south-westerly and anticyclonic air circulation) and respiratory pathologies in winter, with hospital admission values of 1.5 times higher than the average for the same period. A previous study by (McGregor et al. 1999) concluded that certain air masses (cold and maritime air) can even be indicators of a lower number of admissions for respiratory pathologies because their features favoured the reduction of air pollutants. In another study by (Jamason et al. 1997), the high variability of the number of patients seeking emergency treatment for asthma problems is associated with synoptic situations in autumn that favour the arrival of cold, dry air masses. Respiratory pathologies are some of the most significant causes of morbi-mortality on a global scale (Prüss-Üstün and Corvalán 2006). Consequently, the aim of this study was to analyse the possible links between atmospheric conditions and daily hospital admissions for respiratory diseases in Galicia (Spain) during the winter period. The study begins by identifying the main types of Circulation Weather Types (CWT) between 1 November and 31 March; next, seasonal, monthly and daily variations in the number of admissions for respiratory causes between 2001 and 2011 are analysed; and lastly, a link was established between the atmospheric conditions identified and daily admissions.

Materials and methods

Study area

Galicia, with a land mass of 29,574 km^2, is in the north-west part of the Iberian Peninsula and exposed to the direct influence of the Atlantic Ocean (Fig. 1). Temperatures are moderate all year round due to the influence of the Atlantic. In inland and south-east areas, continental and Mediterranean aspects of the oceanic climate that characterises the whole region generate greater temperature oscillations and more extreme temperatures. Humidity is high throughout the year, and there is abundant precipitation, over 700 mm across the entire region, with average annual figures in excess of 1500 mm along most of the Atlantic coastline. The Autonomous Community of Galicia has 2,747,559 inhabitants (2013 population census) with higher population densities in the western half of the region, specifically in the Atlantic corridor lying between the cities of Ferrol and Vigo. Men account for 48.2 % of the population and women for 51.8 %. About 29.7 % of the population is over 60 years of age, with 29.3 % aged between 40 and 60 years, 25.2 % between 20 and 40 years, and 15.7 % of the population is aged under 20 years.

Daily circulation weather types (CWT)

Classification of atmospheric patterns has been an important topic in climate studies in recent years (Huth et al. 2008). In this study, we made use of a particular classification (Lorenzo et al. 2008) that takes into account daily mean surface pressure data from the National Center for Atmospheric Research (NCAR) reanalysis (Kalnay et al. 1996) (2.5° x 2.5° longitude/latitude spatial resolution).

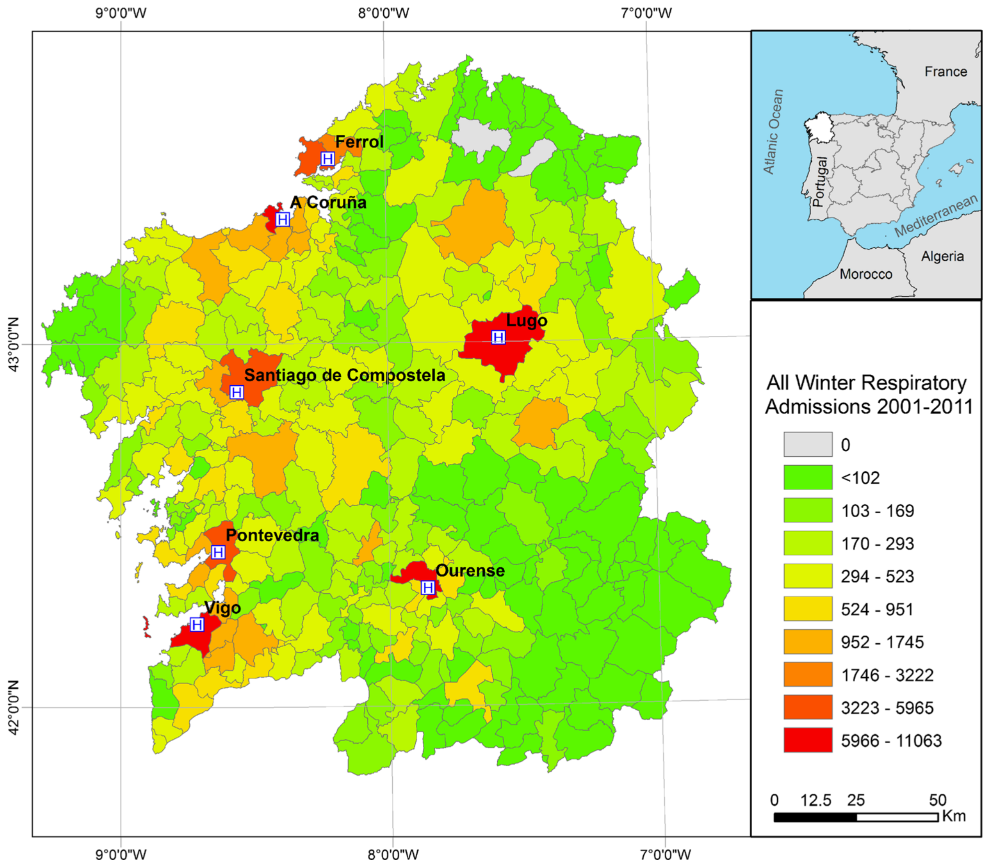

Fig. 1 Location of Galicia and total daily hospital admissions per town due to respiratory causes in winter (2001–2010). Data: SERGAS

We use the daily sea level pressure (SLP) for the period January 2001 to December 2011, NCEP/NCAR Reanalysis of US National Oceanic and Atmospheric Administration (NOAA). This period was conditioned by the availability of hospital admission data. The procedure adopted was developed in (Trigo and Camara 2000), which in turn was adapted from those developed by (Jenkinson and Collison 1977) and (Jones et al. 1993). We calculated the direction and vorticity of near-surface flows, making calculations on a daily basis for the period (2001–2011) for which we have admission data. We assumed possible delayed effects of exposure shown in the previous results of cold temperature on morbi-mortality (Braga et al. 2002; Curriero et al. 2002; Schwartz et al. 2004; Rocklöv and Forsberg 2008; Green et al. 2010). Therefore, we decided to use the time lags of the CWT for the previous 7 days of the current day (lags 1–7). Table 1 shows the frequency of appearance of each of the atmospheric patterns considered in the classification. This table shows the eight directional atmospheric patterns, from north-east (NE), to north (N), the anticyclone (A) and cyclonic (C) situations, and the hybrid patterns in which neither directionality nor vorticity dominate. Thus, there are hybrid cyclone (HC) situations and the hybrid anticyclone (HA) situations. The more frequent situations in this period are the anticyclone situations followed by western (W), south western (SW) and C situations. For the purpose of this study, we took into account only the atmospheric patterns that appeared for at least 40 days, 2.40 % of the time series, to consider all the directional circulation patterns. In order to highlight the particular characteristics of each pattern, we represented the average synoptic situation (Fig. 2). The significance of the directional situations can clearly be seen. The position of the high and low pressures brings different winds to the area of the NW Iberian Peninsula. Thus, for example in the NE situations, a high pressure system is located to the west of Ireland, while low pressures lie over the western Mediterranean, forming an isobar corridor that produces NE winds. In E, SE and S situations, high pressures move to the north of Iberian Peninsula and low pressures are on the Atlantic area, west of Portugal. Depending on the specific strength and position of each one, the situation will be E, SE or S, while SW and W situations are more frequent in winter in the area. In this case, low pressures travel in the north Atlantic and high pressures are located in the area of the Azores. When these high pressure centres move to the north, they contribute to the appearance of NW or N situations. Lastly, in C situations, low pressures dominate the synoptic situation, with no influence of any high pressure system, while A situations present no influence from lows, with high pressures centred over the area of the NW Iberian Peninsula. The three hybrid situations considered (AE, ASW and AW) have the characteristics of E, SW and W, respectively, but with a more marked influence of high pressure.

Hospital admission data

Daily hospital admissions were supplied by the Clinical Coding and Analysis Service at *Servicio Galego de Saúde* (SERGAS), the Galician health service body. The data were obtained from clinical hospitals run by SERGAS in each of the seven principal Galician cities (Fig. 1), for the period between 1 January 2001 and 31 December 2011. Due to the large-scale effect of the CWT, the daily hospital admissions of all cities as the total amount resulting from the addition are used. The spatial origin of the people admitted to hospitals covered all municipalities in Galicia, although most of them came from the healthcare areas where the seven hospitals are located. There are other secondary and local hospitals where the vast majority of inhabitants from the areas furthest away from the cities such as towns and villages in south-eastern Galicia go for treatment. Hospital admission data were classified by pathology, selecting only those of patients admitted for respiratory causes. The International Classification of Diseases (ICD-9) applied in this study were 460–519. The data were then classified by gender and age group (<20, 20–40, 40–60 and >60 years). The analysis focused on the coldest time of year, between 1 November and 31 March from 2001 to 2011, altogether 10 winter seasons. The daily time series of hospital admissions corresponds to count data. This statistical data type is observations that can take only the non-negative integer values. Consequently, the data follows a discrete distribution which can be approximated by the commonly used Poisson distribution. Due to the deterministic components (trend and season) of the daily hospital admissions, a seasonal additive decomposition was applied. The seasonal decomposition of the time series was conducted with the software environment R, version 3.2.1. The Season-Trend-Loess function {stats} was used with a periodic season window and trend window of the whole time series (Cleveland et al. 1990). For statistical significance testing between the variables, we used a Fisher's exact test with a significance level $\alpha = 0.01$. To facilitate the comparison between admissions and weather types, an admissions index (AI) (1) was calculated following the model devised by (McGregor et al. 1999) and later used in similar studies (Pablo et al. 2009, 2013):

$$AI = \frac{Hospital\ Admissions_i}{Winter\ Average\ Admission_y} \cdot 100 \qquad (1)$$

where (i) and (y) represent a specific day and winter season, respectively. This index standardises daily admissions in respect of the average for each winter season, giving a percentage result. Thus, an AI of 150 means that admissions for that day were 1.5 times above the yearly average; and values of less than 100 are for daily admission figures below that average. This rules out the annual variability of anomalies that have arisen throughout the study period.

Confounding factors

In section "Introduction" has been mentioned the existence of confounding variables, such as air pollution, pollen concentrations and influenza. In the present study, it is not possible to incorporate the first two covariates due to a lack of availability and low data quality. Furthermore, only large cities have air quality monitoring stations. A high representativeness of spatial and temporal coverage for this large-scale analysis of the whole Galician territory would be necessary. With respect to the pollen concentrations, the study focuses on winter months, in which pollen is assumed to be low (Khwarahm et al. 2014; Rodriguez-Rajo et al. 2003). The influenza data has been ruled out due to the weekly time resolution and the fact that flu cases are included as a subgroup of respiratory disease in daily hospital admissions. It can be assumed that their influence would be small as epidemic indicator because of the seasonal adjustment.

Results

Circulation weather types (CWT)

To clarify the meteorological characteristics of each of the circulation patterns used in the work, we studied temperature, rainfall, humidity, sea-level pressure and sunshine hours (Fig. 3). Weather stations came from the European Climate Assessment & Dataset (ECAD, www.ecad.eu), in particular, we consider the stations of A Coruña, Santiago, Vigo-Peinador and Pontevedra. These four stations are representative of the seven cities considered in the hospital admission data. Thus, for temperature, the lowest average temperatures were associated with N and NE situations, while SE, SW and AE resulted in the highest average temperatures. It is worth noting that anticyclone and cyclonic situations had a similar average temperature, because high pressure in winter brings cold air from the European continent, leaving low temperatures. In rainfall, the differences between atmospheric patterns were very dependent on the air mass. The situations that brought humid air from the west (SW, W, NW, ASW or AW) together with cyclonic situations that enhanced instability contributed to the appearance of rain, while those situations from the east or the anticyclone situations had close to zero associated rainfall. For the case of relative humidity, the driest situations were associated with SE, and in general with east situations,

Table 1 Frequency of appearance of atmospheric patterns

CWT	Number of days	%
NE	50	3.01
E	44	2.64
SE	56	3.37
S	44	2.64
SW	169	10.16
W	222	13.34
NW	71	4.27
N	40	2.40
C	105	6.31
A	408	24.53
CNE	14	0.84
CE	6	0.36
CSE	10	0.60
CS	13	0.78
CSW	36	2.16
CW	26	1.56
CNW	7	0.42
CN	12	0.72
ANE	29	1.74
AE	42	2.52
ASE	22	1.32
AS	33	1.98
ASW	59	3.55
AW	94	5.65
ANW	33	1.98
AN	18	1.08

while west cyclonic situations were associated with greater relative humidity. As expected, sea-level pressure showed a substantial difference between cyclonic and anticyclonic situations, with anticyclonic situations being associated with the greatest sea-level pressure and cyclonic with the lowest pressures. For directional situations, sea-level pressure was similar, because, as explained above, the area under study is located between the high and low pressures. Lastly, sunshine hours showed the highest values associated with anticyclones and eastern situations, which were the driest periods, while the lowest average values were from western situations.

Hospital admission characteristics

Table 2 shows a summary of the characteristics of the total daily admissions over the seven hospitals analysed. During the study period, between November and March, the daily average admissions rate was 90, somewhat higher than the yearly average of 75.2. Figure 4 shows that the number of hospital admissions for respiratory pathologies was subject to regular and very marked seasonal cycles. The greatest number of admissions occurred during the mid-winter months, with daily averages of 94 in December and 98.1 in January. By contrast, the lowest number of admissions occurred in the summer, with 50 in July and 49.1 in August. This seasonal fluctuation seen in hospital admissions every year appears to be closely linked to monthly temperature variations. In the months with the lowest temperatures, the number of admissions rose notably, reaching almost double the number recorded in the mid-summer months, when temperatures were higher.

Table 2 Characteristics of daily admissions across all seven hospitals in Galicia by groups

	Min.	1st Qu.	Median	Mean	3rd Qu.	Max.	σ
All	5.2	57.5	68.0	68.4	78.3	153.5	16.9
Male	0.1	20.3	25.7	26.0	31.2	65.9	8.5
Female	0.5	35.8	41.8	42.3	48.5	89.8	10.5
<20 years	0.0	6.7	10.0	10.3	13.6	36.6	5.1
20–39 years	0.0	3.1	4.5	4.8	6.2	16.6	2.4
40–60 years	0.0	5.4	7.2	7.4	9.2	22.1	3.0
>60 years	1.5	30.7	39.8	40.2	48.9	113.4	14.0

Analysing only the days on which a higher number of admissions than the average value for the study period (90 admissions/day) were recorded, the monthly distribution clearly shows that those days were concentrated in the months between November and March, in particular December and January. Together, these days represented 45 % of the days with the greatest number of admissions, including the total number of days of the series in which there were more than 140 admissions. It is also clear that between July and September there was no episode with a high number of hospital admissions.

Superimposed on these seasonal cycles, admissions showed high daily variability, with very marked maximum peaks of over 150 admissions per day, double the annual average, all of which occurred in December and January. This daily variation was conditioned by other social and environmental factors as well strictly atmospheric factors. The distribution of hospital admissions between 2001 and 2011 did not show any clear trend; with the exception of the start and end of the period, mean values remain constant (Table 2). The same temporal distribution was shown by the series of admissions by gender, always with higher figures for males. The ratio between men and women showed men were admitted more frequently, with a value of 1.4. Greater differences were obtained when admissions were broken down by age groups, Table 2). The sector of the population aged between 20 and 60 years showed mean values of lower than 10 admissions, with a maximum of 21 and 33 and a variance of below 20. The younger population, aged below

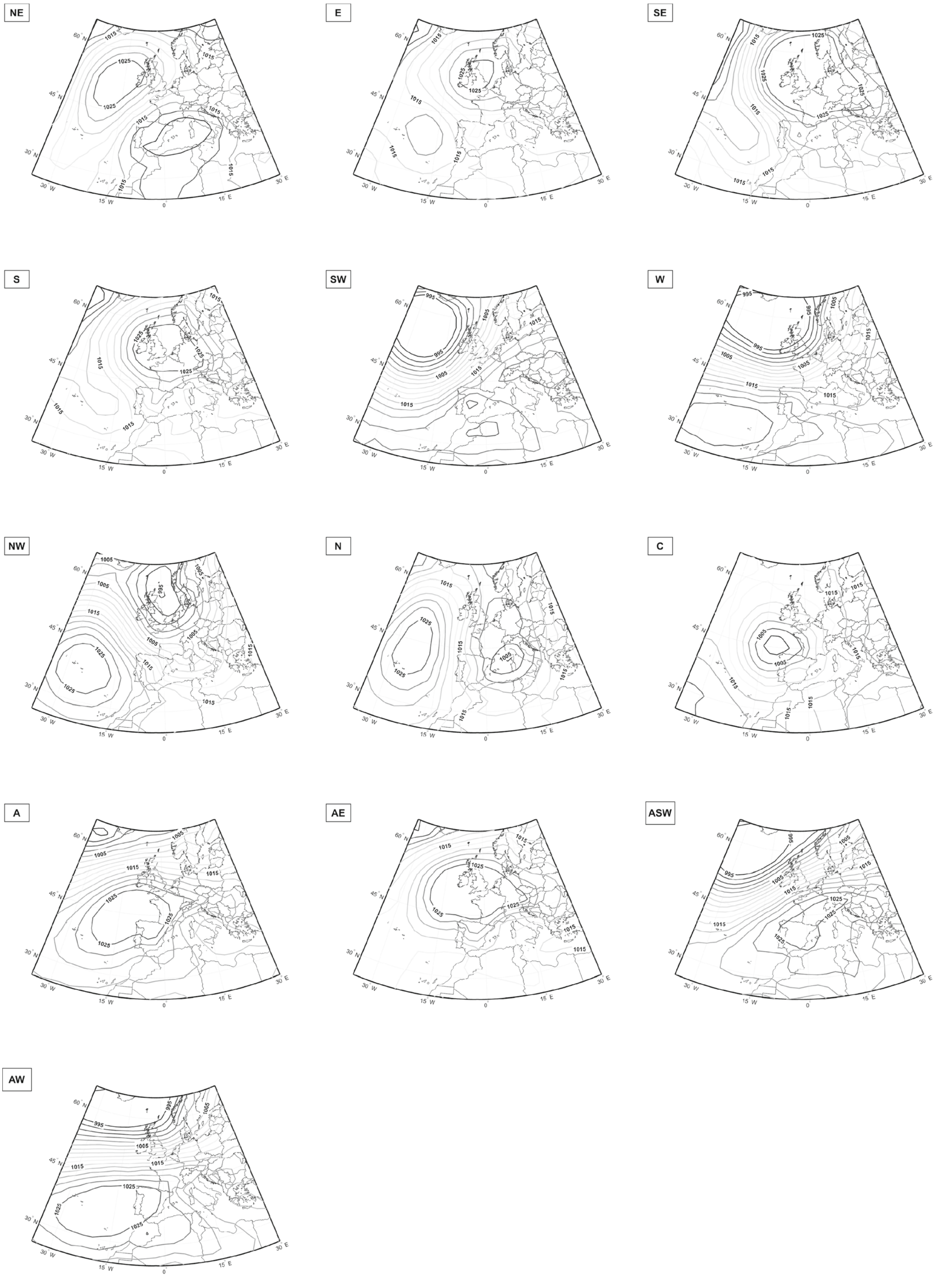

Fig. 2 Average SLP fields characteristic of the 13 main synoptic weather types of the Winter period (contour interval, 2 hPa)

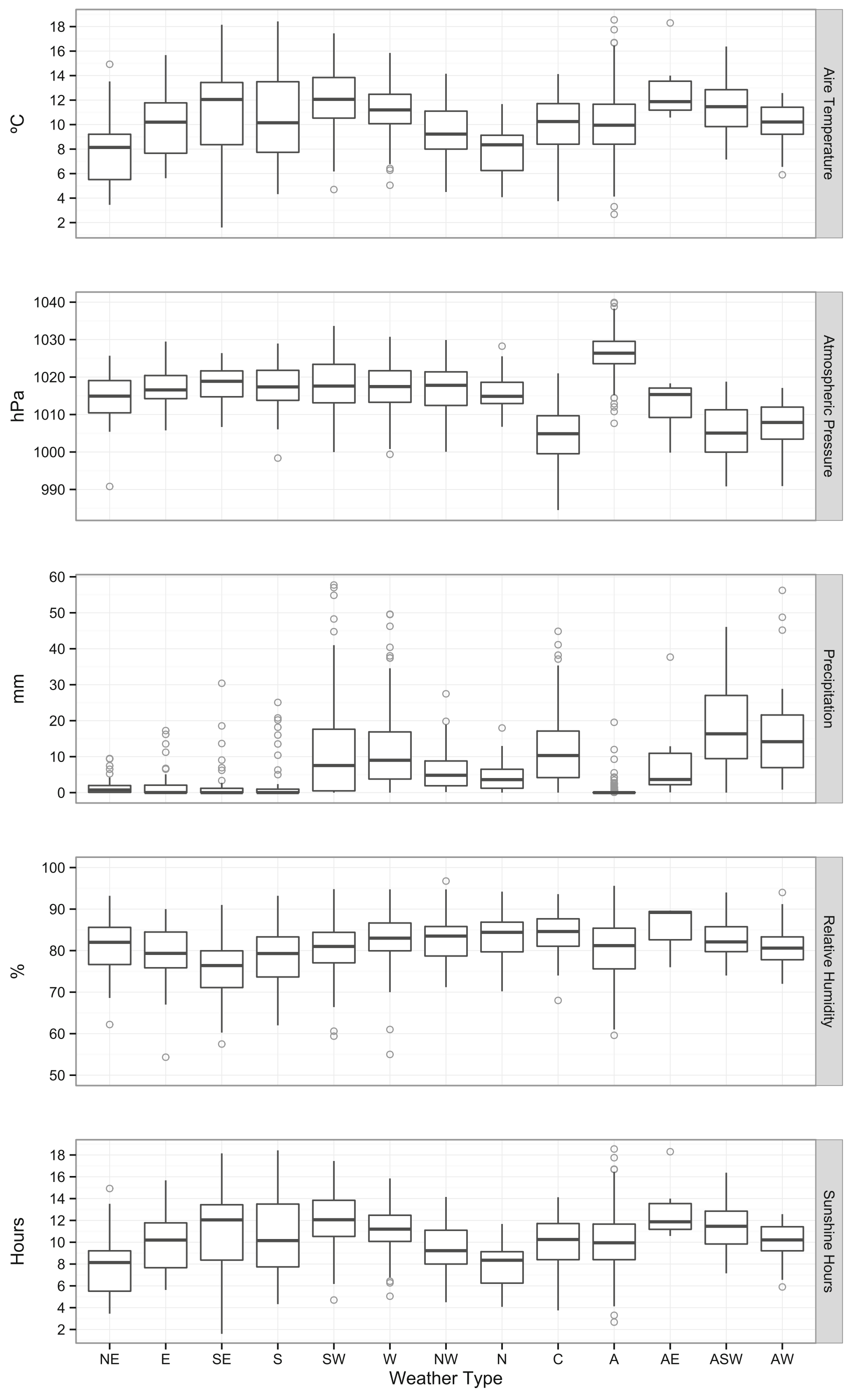

Fig. 3 Climatic characteristic of the 13 main synoptic weather types of the Winter period

20 years, was somewhat more vulnerable, with a mean of 16.5 and daily maximum admissions of 47. But the oldest population group stood out for the high number of admissions; the mean value was 57.5, and on several occasions throughout the study period more than 100 daily admissions were recorded across the whole of Galicia. Compared to a variance of 48.4 for the youngest group, this group of individuals aged over 60 years showed a high dispersion value of 347.5. These figures show, on the one hand, the high vulnerability of this population group to atmospheric factors that could aggravate respiratory pathologies and, on the other hand, a high temporal variability in the number of hospital admissions that may be connected to the variation in weather types. In all age groups, the number of admissions for men was higher than that of women, especially in the 40 to 60 years age group, where it was double. The distribution of the number of admissions during weekdays showed a clear difference between working

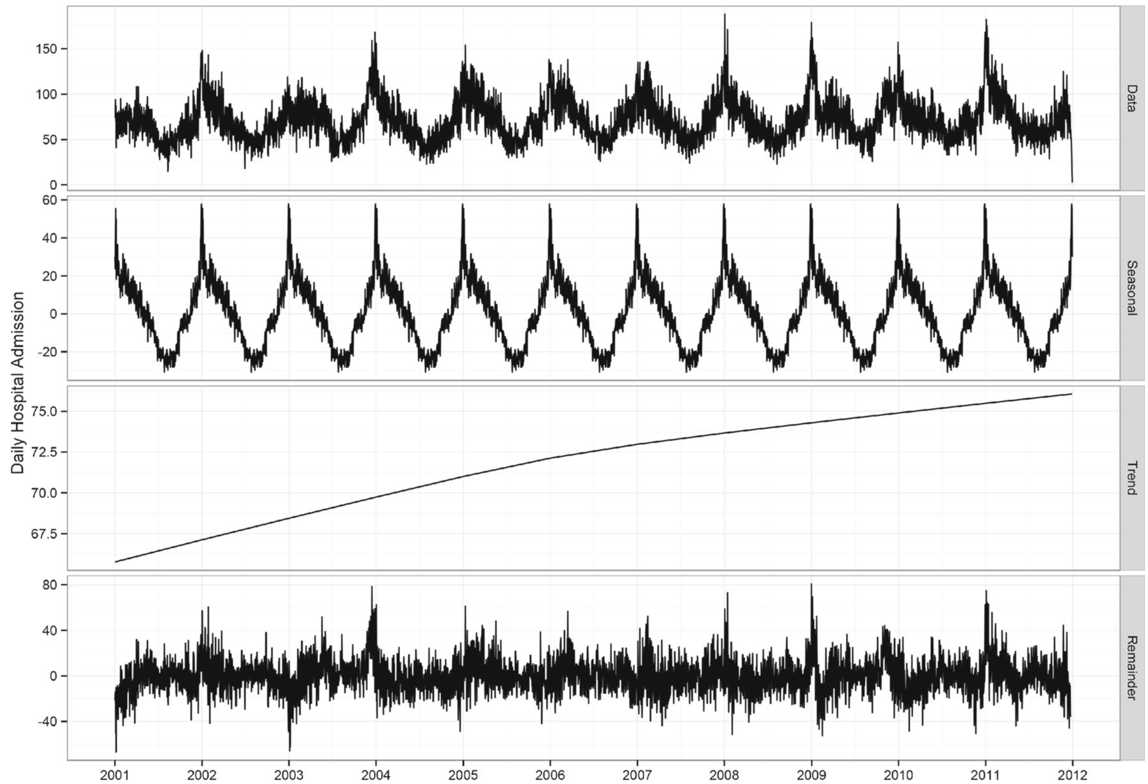

Fig. 4 Seasonal decomposition of total daily hospital admissions due to respiratory causes between 2001 and 2011 in Galicia

days, with mean values of between 93 and 98, and weekends; during Saturday and Sunday, there was a notable fall in the number of admissions, with mean values of 80.3 and 70.8.

Admission indices and CWT associations

The association of hospital admissions and circulation patterns is shown in Tables 3 and 4. The probability of having a great number of respiratory hospital admissions is associated with eastern (E) weather circulation situations. This high probability must be associated with the meteorological characteristics of these situations that can be described as dry and cold. C and AW situations also have a high probability. If we consider the probability of having an admission index greater than 125, we must take into account AE and W situations. W correlation was particularly crucial because it appeared more frequently than the other situations. The W and AW patterns were associated with rain, high humidity and also mild temperature. Therefore, two different scenarios appear in the region that contributes to high prevalence of respiratory illness in winter: dry and cold associated with E or AE situations being the most important, or humid and mild temperature associated with W or AW. If we distinguish between genders, we can see that E situations were more likely to result in an admission index higher than 150 to male patients; AW situations were more problematic for female patients, but with a little difference with E situations. We also divided the population into four different age categories. The weather types that have a greater probability of causing more respiratory hospital admissions for people younger than 20 years old were W and E. Patients with ages between 20 and 40 years had the greatest probability of an admission for respiratory illness associated to W and AE situations. Nevertheless, this is the group that had lower daily admission values and therefore the admission index showed a wide variation. When we looked at patients with ages between 40 and 60 years, we found that AW situations were more dangerous, but E and AE situations had almost a hight risk percentage. Finally, when we studied the population aged over 60 years, the situation that presented the greatest frequency of an admission index over 150 were C situations. Obviously, older people suffered respiratory illness more frequently and therefore the results for this group were more homogeneous than for the whole population. The hybrid situation AW next to E and W situations has also a significant percentage with a value greater than 150 in the admission index. If we consider these associations taking into account a time-lag between the circulation pattern and the hospital admission (Table 5), we can see that the highest admissions were associated with E situations two or 6 days earlier. Also, ASW situations have a small time-lag between

Table 3 Conditional probabilities (%) by gender in the number of days associated with each circulation weather type for respiratory admission indices (AI) classes

ALL	NE	E	SE	S	SW	W	NW	N	C	A	AE	ASW	AW
<100	54.17	52.38	48.21	42.86	45.14	41.45	56.92	55.56	48.86	60.21	60.00	54.55	39.76
100–125	31.25	23.81	39.29	45.24	38.19	34.72	33.85	27.78	30.68	28.27	22.50	30.91	43.37
12–150	12.50	14.29	10.71	7.14	11.11	18.65	9.23	13.89	12.50	8.64	15.00	12.73	9.64
≥150	2.08	9.52	1.79	4.76	5.56	5.18	0.00	2.78	7.95	2.88	2.50	1.82	7.23
Women	NE	E	SE	S	SW	W	NW	N	C	A	AE	ASW	AW
<100	56.25	40.48	51.79	42.86	42.36	41.45	70.77	44.44	50.00	58.38	57.50	45.45	39.76
100–125	22.92	35.71	33.93	40.48	30.56	33.16	15.38	36.11	27.27	26.44	17.50	34.55	33.73
125–150	18.75	14.29	8.93	9.52	19.44	17.10	10.77	13.89	13.64	9.69	22.50	18.18	16.87
≥150	2.08	9.52	5.36	7.14	7.64	8.29	3.08	5.56	9.09	5.50	2.50	1.82	9.64
Men	NE	E	SE	S	SW	W	NW	N	C	A	AE	ASW	AW
<100	52.08	50.00	42.86	38.10	52.08	45.60	50.77	52.78	40.91	62.57	60.00	52.73	44.58
100–125	37.50	30.95	41.07	47.62	33.33	32.12	40.00	38.89	35.23	26.44	25.00	27.27	36.14
125–150	6.25	9.52	16.07	9.52	10.42	13.99	7.69	5.56	15.91	7.59	10.00	16.36	13.25
≥150	4.17	9.52	0.00	4.76	4.17	8.29	1.54	2.78	7.95	3.40	5.00	3.64	6.02

1 and 3 days. However, W and C situations and admissions were more simultaneously produced. In Finland, (Mäkinen et al. 2009) observed that between 3 days and 2 weeks before the start of several episodes with a major increase in respiratory tract infections, there was a significant drop in temperature and humidity.

In fact, events with the highest number of admissions in the series analysed in Galicia took place several days

Table 4 Conditional probabilities (%) by age in the number of days associated with each circulation weather type for respiratory admission indices (AI) classes

<20	NE	E	SE	S	SW	W	NW	N	C	A	AE	ASW	AW
<100	52.08	52.38	44.64	61.90	54.86	53.89	50.77	58.33	53.41	53.93	75.00	52.73	45.78
100–125	18.75	19.05	23.21	9.52	14.58	15.54	18.46	11.11	19.32	22.25	10.00	20.00	22.89
125–150	14.58	9.52	16.07	14.29	15.97	9.33	13.85	16.67	15.91	11.26	10.00	10.91	15.66
≥150	14.58	19.05	16.07	14.29	14.58	21.24	16.92	13.89	11.36	12.57	5.00	16.36	15.66
20–39	NE	E	SE	S	SW	W	NW	N	C	A	AE	ASW	AW
<100	58.33	50.00	44.64	50.00	50.69	53.37	56.92	50.00	47.73	61.78	50.00	56.36	46.99
100-125	16.67	11.90	28.57	16.67	21.53	15.54	13.85	22.22	20.45	13.35	25.00	18.18	22.89
125–150	8.33	21.43	10.71	16.67	7.64	9.84	10.77	13.89	19.32	12.57	5.00	16.36	12.05
≥150	16.67	16.67	16.07	16.67	20.14	21.24	18.46	13.89	12.50	12.30	20.00	9.09	18.07
40-60	NE	E	SE	S	SW	W	NW	N	C	A	AE	ASW	AW
<100	50.00	42.86	51.79	42.86	44.44	44.56	53.85	50.00	56.82	55.24	55.00	65.45	42.17
100–125	29.17	28.57	21.43	28.57	17.36	23.83	21.54	13.89	22.73	24.87	15.00	14.55	22.89
125-150	14.58	11.90	8.93	19.05	22.22	18.13	15.38	25.00	10.23	10.21	20.00	9.09	12.05
≥150	6.25	16.67	17.86	9.52	15.97	13.47	9.23	11.11	10.23	9.69	10.00	10.91	22.89
>60	NE	E	SE	S	SW	W	NW	N	C	A	AE	ASW	AW
<100	52.08	57.14	51.79	42.86	46.53	37.31	52.31	58.33	40.91	59.42	55.00	47.27	43.37
100–125	33.33	23.81	35.71	38.10	29.17	37.31	38.46	25.00	26.14	24.61	22.50	32.73	32.53
125–150	8.33	9.52	8.93	14.29	15.97	14.51	9.23	13.89	21.59	11.52	15.00	12.73	14.46
≥150	6.25	9.52	3.57	4.76	8.33	10.88	0.00	2.78	11.36	4.45	7.50	7.27	9.64

Table 5 Descriptive statistics on mean admissions indices (AI) depending on time lag (an AI value of 100 indicates an average winter level of admissions

Lag	NE	E	SE	S	SW	W	NW	N	C	A	AE	ASW	AW
0	97.68	103.29	99.31	102.76	101.81	105.40	96.67	97.82	105.83	94.88	95.76	99.93	104.74
1	101.19	103.17	107.25	100.86	103.85	103.28	94.54	100.80	100.10	95.90	103.63	104.96	98.20
2	100.90	109.55	103.81	101.66	102.29	102.77	94.63	103.93	100.28	95.93	104.10	104.25	99.19
3	99.39	111.48	101.37	99.14	104.34	100.51	101.94	92.67	99.87	96.76	104.25	107.12	97.43
4	97.17	107.04	99.92	103.72	101.82	101.60	98.25	97.66	97.31	99.01	99.81	102.78	101.24
5	99.31	108.49	99.55	97.13	96.92	102.39	93.46	98.30	99.61	99.82	100.77	102.90	103.44
6	103.00	105.86	94.75	105.09	95.39	102.30	96.78	95.25	99.70	100.22	89.61	99.07	102.64
7	101.31	104.39	97.42	101.64	99.42	97.93	96.02	98.25	98.80	100.23	103.15	96.36	102.38

after there were marked drops both in temperatures and in humidity. An example is given below. Figure 5 shows the daily number of admissions between 10 December 2010 and 30 January 2011, together with the temperature variations, maximum and minimum, and minimum humidity in the city of Santiago de Compostela. On 3 January 2011, there were 182 admissions for respiratory diseases in the seven hospitals analysed. This was the second major peak in admissions of the whole series. On 24 December, the atmospheric situation over the Iberian Peninsula favoured the entry of very cold and dry masses of air coming from the interior of the European continent (Fig. 6). In Galicia, the SE situation resulted in a drop in temperatures over the following days, especially minimum temperatures, which in Santiago reached −2°C; air humidity also fell, reaching a minimum of 38 % on 27 December. For several days with a stable atmospheric situation, the population was affected by cold, dry air that caused, as can be seen from the figure, a continued increase in hospital admissions from 27 to 30 December, when there was a peak of 160

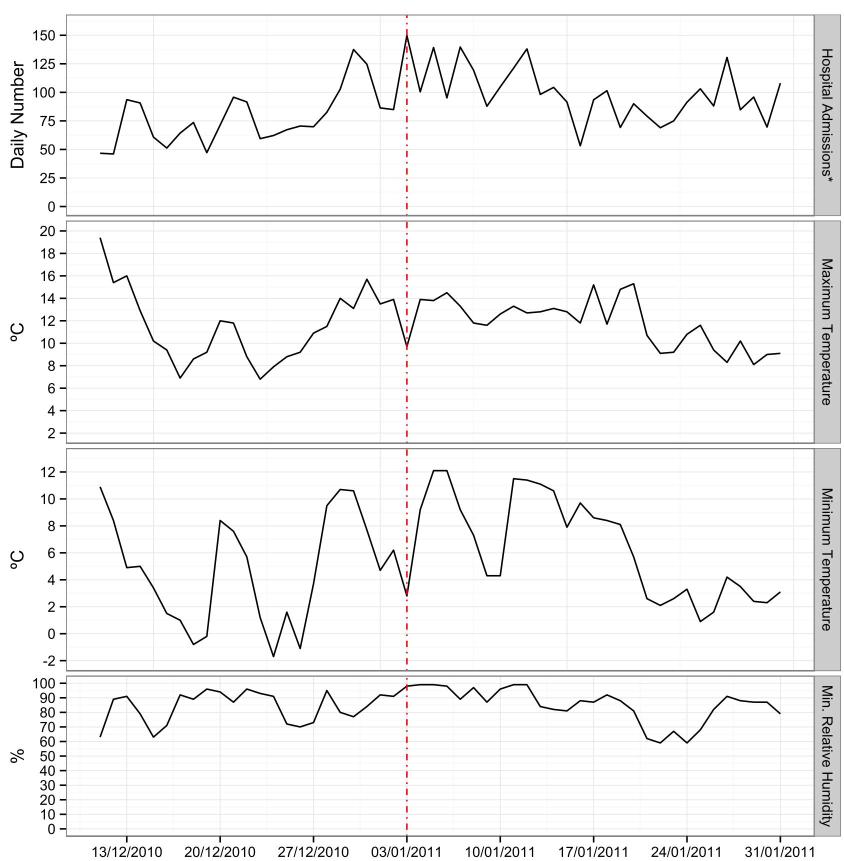

Fig. 5 Daily number of admissions between 10 December 2010 and 30 January 2011, variations in temperature and minimum humidity in the city of Santiago de Compostela. *Season-trend adjusted data; *red*, *dashed line*: relative maximum of daily hospital admissions. Data: SERGAS, Meteogalicia

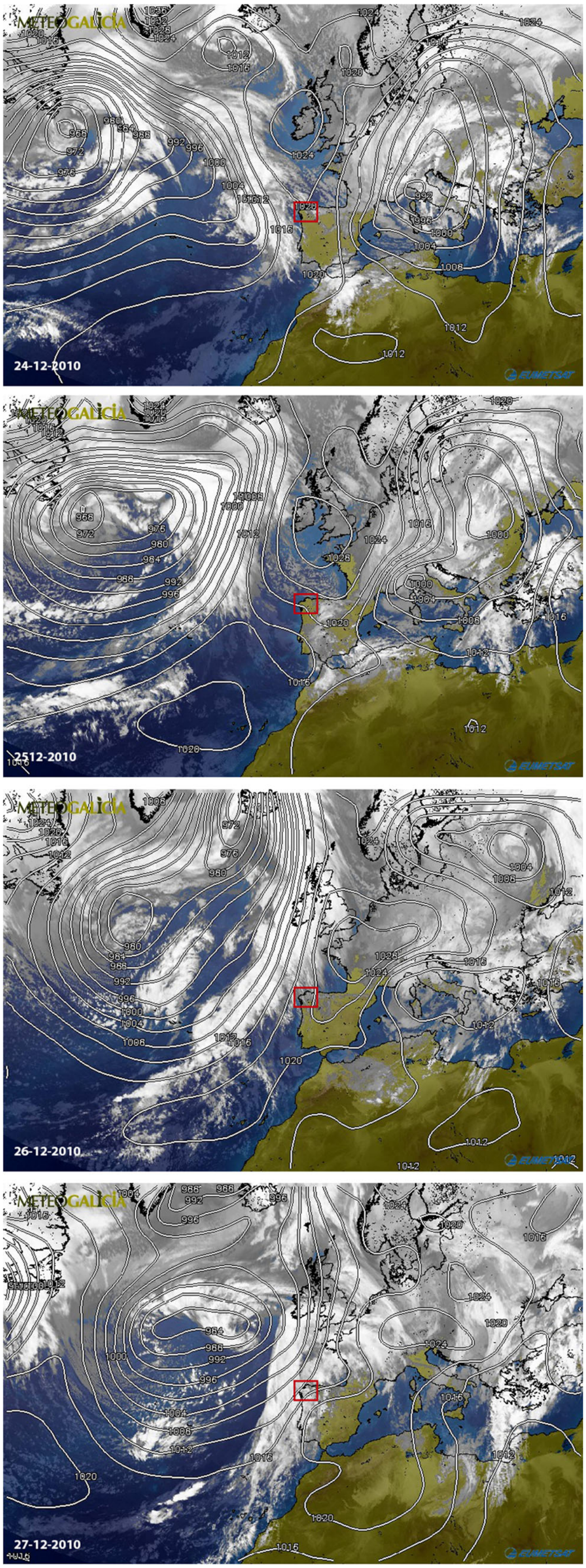

Fig. 6 Synoptic situation on 24–27 December 2010. Source: Meteogalicia

admissions. After a brief recovery, temperatures once again fell sharply in the first few days of January 2011, which led to another peak of admissions, this time reaching 182 cases.

Discussion

The seasonality of respiratory infections in Galicia shown in Fig. 4 is linked mainly to monthly temperature fluctuations. Numerous studies show that exposure to cold air causes an increase in the incidence of URTIs (upper respiratory tract viral infections), due to cooling of the nasal airway (Eccles 2002; Lofgren et al. 2007; Polozov et al. 2008; Mäkinen et al. 2009; Tamerius et al. 2011; Kalkstein and DeFelice 2014). The reason for this is that breathing in cold air leads to a reduction in nasal temperature and cooling of the nasal epithelium, thereby inhibiting respiratory defences against viral infections. In areas with mild climate in both hemispheres, there is always a peak in respiratory diseases during the winter months; these months are when more than 200 different viruses causing URTIs appear. As a result of this, (Eccles 2002) estimated that around 33 % of the seasonal increase in mortality in the United Kingdom is associated with respiratory diseases linked to infection; in fact according to this author, there is a growing body of evidence to suggest that part of the increase in mortality from cardiac causes can be attributed to respiratory infections. Together with temperature, humidity is another major environmental factor closely linked to respiratory diseases. A number of studies have shown that the survival and transmission of the viruses is favoured by a drop in temperatures and a lower relative and absolute air humidity (Lowen et al. 2007; Polozov et al. 2008; Shaman and Kohn 2009; Tamerius et al. 2011). In temperate regions, it has been observed on numerous occasions that lower humidity can lead to seasonal flu epidemics (Shaman et al. 2010; Tang et al. 2010). A cold, dry atmosphere, together with low solar radiation, favours virus transmission and also leads to weakened respiratory system defences. The sharp drop in relative humidity occurring in indoor spaces due to heating systems, coupled with cold outdoor temperatures, also encourages viruses to propagate. Dryness in the nasopharyngeal and tracheal passages also make them more susceptible to viral infection. All this would explain the high admission indices obtained in Galicia for winter E and SE situations, which usually bring a drop in temperatures and, above all, in humidity. Other types of respiratory diseases such as pneumonia increase due to exposure to cold and high humidity. While cold paralyses the cilia's ability to flush foreign bodies from the respiratory mucous in the bronchial tubes, humidity encourages the proliferation of fungus and bacteria that can cause sinusitis, asthma, bronchitis and pneumonia. (Shaman and

Kohn 2009) emphasised that this proliferation of pathogenic germs is greater in poorly ventilated environments. So, high humidity and poor ventilation, which in winter is usually the case for enclosed spaces in many homes, are commonly linked to the incidence of pneumonia. This fact could explain the increase in admissions, which, as shown in Table 3, also occurred in the study period, coinciding with AW,ASW, W and C atmospheric situations, resulting in high levels of environmental humidity.

Conclusions

The number of hospital admissions in Galicia due to respiratory causes shows a high daily variability, although with regular seasonal cycles. There was a higher number of admissions in winter, between November and March (90 admissions on average compared to the annual mean of 75). This was also a period in which all the events with the highest numbers of admissions, over 140 per day, was concentrated. Superimposed on these cycles were maximum daily peaks with values greater than 150 admissions, influenced by atmospheric factors as well as social and environmental factors (morphology and urban heat island, air quality, income or housing characteristics). The over 60s age group showed the highest admission figures, which might be explained by the high vulnerability of this population group to atmospheric factors. The highest probability of a high number of hospital admissions for respiratory causes occurring in all the age groups analysed was linked to E situations (E and AE). These situations produce a type of cold and dry weather that favours virus transmission and leads to weakened respiratory system defences. It was also found that on numerous occasions the effects of E situations on the number of hospital admissions were delayed by between 2 days and 1 week. Finally, AW, ASW, W and C situations caused an increase in the total number of admissions with moderate frequency, possibly due to humid, rainy weather favouring the proliferation of fungus and bacteria. Given that synoptic situations can be forecast several days in advance, knowledge of these links might in the future be applied to making improvements in public health systems, minimising possible scenarios of hospitals being overwhelmed and helping to optimize resources. For future research, the synoptic climatological approach should be extended to the estimation of relative risks associated with the circulation weather types. In addition, the biometeorological contrast between different circulation weather types could be more important on the morbi-mortality than the particular synoptic situation.

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